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Recent progress in solar thermal energy storage using nanomaterials

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ABSTRACT

Use of thermal energy storage (TES) materials in solar collectors is known to be the most effective way of storing thermal energy. The most conventional and traditional heat storage element is water. However, due to low thermal conductivity (TC) in vapor state its applications as a heat storage medium are limited. An alternative option is to utilize organic and inorganic TES materials as they both operate at low and medium temperature ranges. Organic TES materials such as paraffins are non-corrosive and possess high latent heat capacity. On the contrary, inorganic TES materials possess high density and appreciable specific heat capacity (SHC). Due to rapid progress and advancement in nanotechnology, varieties of nanomaterials were dispersed in various base fluid(s) to enhance thermo-physical properties. This review paper presents the current status and future development trends of TES materials. Furthermore, an extensive research on enhancement of TC and SHC of various TES material doped with nanomaterials has been discussed.

Contents

1. Introduction

Utilization of energy has a key role in the development of human society. Among other energy sources, electricity is a vital part of maintaining a successful society. Electrical energy has catalyzed the evolution of society in many ways. According to British Petroleum statistical review, global electrical energy needs continue to grow and about 87% of energy production is through fossil fuels as shown in Fig. 1 [1]. From Fig. 1 renewable energies such as wind, solar, biofuels and geothermal etc. accounts for 2.69% of global

Abbreviations: TES, thermal energy storage; SWH, solar water heating; PCM, phase change material; HTF, heat transfer fluid; PV, photo-voltaic; PV/T, photo-voltaic/thermal; EG, ethylene glycol; NP, nano particle; CPSC, concentrating parabolic solar collector; CNT, carbon nano tube; MWCNT, multi walled carbon nano tube; f-MWCNT, functionalized multi walled carbon nano tube; SWCNH, single walled carbon nano horn; ExG, expanded graphite; FPC, flat plate collector; DSC, differential scanning calorimetry; SEM, scanning electron microscope; TE, thermal efficiency; TC, thermal conductivity; SHC, specific heat capacity; LHS, Latent heat storage

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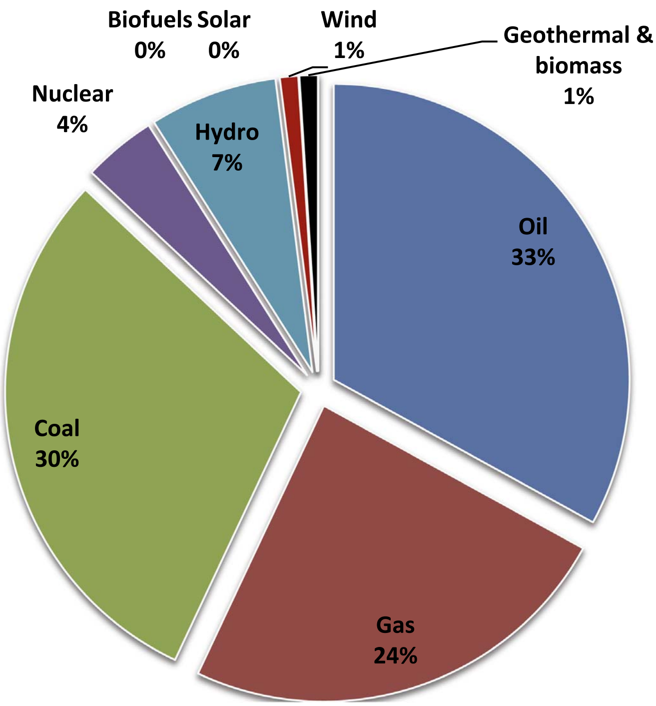

Fig. 1. Global energy consumption in 2013 [1].

energy needs. In order to preserve natural resources and environment, one-third of the world's energy by 2050 will need to come from solar, wind, and other renewable resources.

Therefore, developments in the renewable energy has attracted attention of many researchers, with a view to find an alternative form of sustainable energy [2]. Renewable resources are widely available, environmental friendly and cause little or almost no pollution. However, the biggest challenge in utilizing renewable resources is that it depends on atmospheric conditions, geographical location, economics and safety considerations [3].

One of the efficient ways to utilize solar energy is to make use of solar collectors. Solar collectors convert solar energy into internal heat energy of the system or of fluid. There are three types of solar collector technologies: (i) photo-voltaic (PV) collector, (ii) solar thermal collector and (iii) photo-voltaic/thermal (PV/T) collector [4]. PV collector converts solar radiation into electricity by using semiconductor materials such as Si, SiO_2, GaAs, CuS, etc. The electrical energy produced by PV collector can be used for variety of applications. PV/T collector is a hybrid of PV and thermal collector which absorbs solar radiation and converts it into electricity and thermal energy (using materials such as Al, Cu and polyethylene napthalate). In solar thermal collectors, solar energy is transferred as heat energy to working fluids such as water, ethylene glycol (EG) and etc. [5]. In this paper, the review is restricted to circulating fluids either drawn directly as hot water or to heat transfer fluids (HTF).

Generally, water is being used as thermal storage element in solar water heating (SWH) systems for household applications. However, the main drawbacks of using water are low operating temperature, small duration of TES and low TC. Research has been carried out to enhance TC of water by doping of nanomaterials to use in solar collectors [6]. Ionic liquids such as 1-butyl-3-methylimidazolium hexaflurophosphate and 1-hexyl-3-methylimidazolium tetrafluoroborate etc. have been utilized as HTF in solar collectors [7,8]. Ionic liquids possess advantages over conventional fluids of high operating temperature range, TC and SHC. During the past four decades phase change materials (PCM) are gaining more attention as HTFs. PCMs are mainly classified as organic (such as paraffin wax, ketones and fatty acids etc.) and inorganic materials (such as nitrates, carbonates and hydroxides etc.). To maximize the solar TES, PCM serves as a better choice. Furthermore, advances in nanotechnology led to the synthesis of novel nanoparticle which improves thermal performance of base fluids, paraffins and molten salts [9]. Several investigations have been reported to enhance TC of base fluids, paraffins and molten salts through doping on nanomaterials [10,11].

2. Solar thermal energy storage

Thermal energy collected by solar collectors needs to be efficiently stored. Solar energy is available only during the day and its application requires efficient TES materials. Thus, the excess thermal energy collected during the day time could be stored for later use during the night [12]. The important factors/parameters for TES materials are (i) High thermal storage capacity, (ii) Low cost and low thermal energy loss (iii) High TC and (iv) Eco-friendly [13]. Fig. 2 illustrates the classification of the TES techniques. The basic types of TES techniques are (i) Sensible heat storage, (ii)

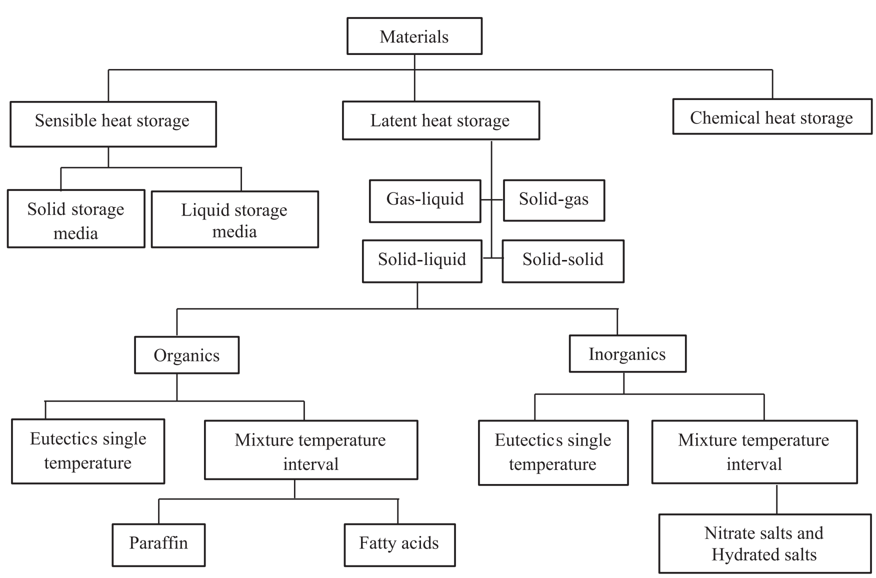

Fig. 2. Classification of latent heat materials, with phase change solid-liquid [14,15].